THE MECHANICAL DESIGN, FABRICATION, AND PERFORMANCE OF THE DCCT FOR TPS

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Abstract

DC current transformers (DCCT), and their mechanical structure, welding of dissimilar materials of the DCCT chamber, and testing of the electronic and vacuum performance, have been designed and fabricated for Taiwan Photon Source (TPS). In the structure, a ceramic break disc is provided and is located between two ends of the beam duct. The electrical connection path is interrupted in the beam duct adjacent to the transformer to avoid the sensor measuring the wall current and other unnecessary circulating currents. To measure the average beam current, the DCCT toroid is independently installed outside the vacuum beam duct. To decrease the influence of the external magnetic field on the sensor, two layers of μ-metal shell are installed. The performance and progress of the DCCT are described in this paper.

INTRODUCTIONS

The electron beam current is a fundamental and important parameter for a synchrotron facility. A DC current transformer has therefore been widely used in world synchrotron accelerators as a tool for research and for precise measurement of the DC signals and low-frequency signals of the beam in the electron-storage ring. The New Parametric Current Transformer (NCPT) is the latest evolution of the Unser Transformer, commonly called DCCT, developed at CERN in 1966 by Klaus B. Unser [1-2]. The wide bandwidth and high resolution of the DCCT provide information about the average beam intensity, injection efficiency and beam lifetime in storage rings.

Because of vacuum baking considerations, an in-flange NCPT was not considered; the in-air type was hence required, with the effort of its mechanical design at TPS. Apart from the beam duct supports, to achieve the installation and mounting of the DCCT toroid, a mechanical support was designed for the bushing of the toroid. To connect the ceramic break disc, beam ducts and flanges, part of the components had to be fabricated and the performance of the DCCT tested.

In this paper, we describe the composition of the DCCT, including the ceramic break disc, vacuum beam duct, DCCT toroid, and its fabrication and performance testing.

DC CURRENT

Figure 1 shows a schematic diagram of the DC current transformer, which consists of seven parts, described as follows:

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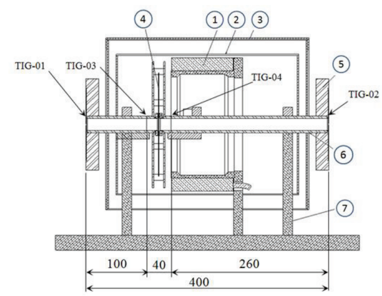
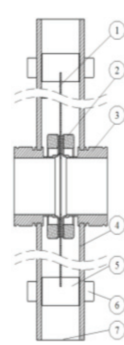


Figure 1: Schematic diagram of a DC current transformer: 1. DCCT toroid, 2. μ-metal, 3. μ-metal, 4. ceramic break disc, 5. 100CF flange, 6. beam duct, 7. Support.

Ceramic Break Disc

The DCCT ceramic break disc assembly, as shown in figure 2, consists essentially of a ceramic disc, ceramic backup rings, sleeves, cover plates, ceramic post and so forth. A ceramic disc was precisely machined and polished as control to outside diameter 172 mm, thickness 0.5 mm; the ceramic backup rings were also subjected to the same processes to fit the required dimensions. Both ceramic components were metalized with a layer of Ag-Cu-Ti alloy, and then electroplated a layer of Ni before brazing, These ceramic materials are 99.5 % alumina Al_2O_3 according to the requirements for ultra-high vacuum. The sleeves were installed between the ceramic disc and the backup ring, which were joined with vacuum brazing – a nickel-iron alloy with 29 % Ni, 17 % Co and 54 % Fe. As the expansion characteristics of Kovar match alumina ceramics, it is commonly used as the metal for ceramic bonding. Four cover plates were mounted on the groove of the sleeve; a ceramic spacer was then adopted to fix it. The outer edge of the cover plates were covered with a layer of polyimide tape to protect the ceramic disc that is damaged by foreign objects.



Items	Description
1	Ceramic break disc
2	Ceramic backup ring
3	Kovar sleeves
4	Covers plates
5	Ceramic post
6	Screws
7	Tape

Figure 2: Schematic diagram of a ceramic break disc.

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Vacuum Beam Duct

The vacuum beam duct is made of 316L stainless steel as the material of the chamber. The cross-sectional shape of the beam duct is racetrack type; the internal sectional and external dimensions of the beam duct are width 68 × height 20 mm and width 76 × height 28 mm; their lengths are 260 and 100 mm, respectively, as shown in figure 1.

DCCT Toroid

The DCCT toroid (Bergoz Instrumentation, BI, New Parametric) has been evaluated and positioned on the storage ring as the beam current monitor at TPS. The NPCT functions on the principle of the zero-flux DC Current Transformer and is an evolution of the Unser transformer, commonly called a DCCT. The Parametric Current transformer is used on most particle accelerators in the world to measure the average beam current; it is an essential instrument for machine tuning and commissioning. The NPCT construction is of 'in-air' type; its mechanical design was undertaken at TPS.

The NCPT works on the principle of detection of the second harmonic. Two cores are modulated to deep saturation in opposite phase. A primary DC current flowing through the cores shifts the working point of the cores to opposite polarity, which generates a second harmonic of the modulation frequency. The primary current AC component is detected with an AC Hereward transformer. The two circuits are cascaded in a common feedback loop to generate a magnetic flux that always cancels the primary current flux. The NPCT output is the voltage developed by the feedback current passing through a precision resistor [1].

FABRICATION

Welding

According to the composition of the DCCT described above, four welds must be made with the tungsten inert-arc welding method, without a filler metal, as shown in figure 1. The parts should be properly cleaned before welding. The TIG-01 is the 100CF flange and TIG-02 is the beam-duct welding, because the flanges belong to the unrotatable type at the ends, and to connect with the upstream and downstream vacuum system. Care must be taken with the perpendicularity between the beam duct and the surface of the knife edge of the flange, which must be measured after welding. The measurement results are shown in figure 3 and table 1.

Figure 3: Measurement status after welding.

Table 1: Dimension Check of DCCT Chamber Componets

Position	DCCT creamic	Beam duct(s)	Beam duct(l)	Total length
1	39.94	100	260.09	400.03
2	39.93	100.01	260.07	400.01
3	39.92	100.01	260.09	400.02
4	39.95	100	260.05	400

TIG-03 and 04 belong to the Kovar/ SS316L dissimilar material welding. To diminish the effect of the welding heat, both the Kovar tube of the ceramic break disc and vacuum beam duct have a groove machined at the weld side. The weld was designed and an image of the welded macrostructure is shown in figure 4a and b.

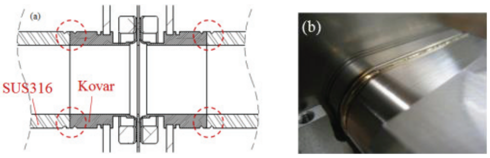

Figure 4: Design for Kovar/SS316L dissimilar welding.

In the TIG-03 and -04 welding, the positioning fixture was completed to install and to weld these components, as shown in figure 5. As the fixture can precisely adjust and fix the position of these components, the spot welding was performed in the TIG-03 and 04 weld before circumferential welding. After welding, all welds were tested for leakage (Alcatel-180td); the results show the rate of leakage to be less than 1.6×10^{-10} mbar L s^{-1}.

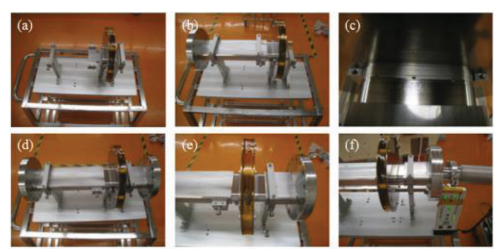

Figure 5: DCCT chamber components positioned to install and weld.

Assembly

The toroid of the DC current transformers was installed in air over the vacuum beam duct, and an aluminium alloy sleeve was adopted as the internal support. The vacuum beam duct was crossed through the toroid, and was then installed in the fixture plate. The toroid was near the ceramic break disc of the vacuum beam duct; the distance is 10 mm.

As there are various magnetic perturbations in the surrounding equipment, μ-metal material was chosen as a shield to protect the DCCT against those magnetic perturbations. To decrease the influence of the external magnetic field on the sensor, two layers of μ-metal shell are installed and secured with screws in the support frame; both ends of the external layer are connected to the vacuum beam duct, as shown in figure 1.

TESTING THE PERFORMANCE

Electronic Testing

The electronic testing includes measurement of capacitance, an insulation test, a magnetic shielding test and a signal test.

The capacitance of a parallel plate capacitor depends on area *A* of the plates and their separation *d*. The capacitance is defined as

$$C = \frac{\varepsilon A}{d} = 8.854 \times 10^{-12} F \qquad (1)$$

According to equation 1, we calculate the theoretical value of the capacitance of the ceramic break disc, which is 4.71 nF. The capacitance of the vacuum beam duct (including the ceramic break disc) was measured with a precision LCR meter (Hewlett Packard 4284A) to be 3.94 nF, as shown in figure 6(a).

The insulation of the vacuum beam duct (including the ceramic break disc) was tested with DC high-voltage equipment (Biddle Instruments High-Voltage), with the input voltage from DC 200 V to 500 V in the vacuum beam duct end, the another end connected to ground, as shown in figure 6(b). The test results show the insulation resistance more than $1\times10^{10}\,\Omega$ at input voltage from DC 200 V to 500 V.

Figure 6: (a) Measurement of capacitance of the DCCT assembly, (b) Testing the high-voltage insulation of the DCCT assembly.

The mechanical structure of the shielding was previously described. For the shielding test we adopted a magnetometer (Walker Scientific, INC. Fluxgate Magnetometer FGN-4D2N) to detect the shielding effect, as shown in figure 7a and b. The detector was set outside and inside the μ-metal shielding layer. The results show that the shielding layers have insulating and protecting effects. When the detector was set outside the shielding layers, the value was larger than when installed inside.

Figure 5: Shielding test of the DCCT assembly.

Vacuum Testing

As the DCCT will be installed in the vacuum system of the electron storage ring of TPS, it needs a pre-vacuum performance test to fit the UHV requirement. The DCCT system was installed in a pumping system, including dry and turbo molecular pumps and ion gauge, to be pumped and to record the pressure during baking; thermocouples were distributed and measured the temperature in the toroid, ceramic break disc, vacuum beam duct and so forth, as shown in figure 8a and b respectively.

Figure 8(a) shows the distribution of the bake-out temperature for the DCCT chamber. The DCCT of 'in-air' type design allows baking of the beam duct at temperatures up to 200 °C. As the temperature of the toroid sensor will not exceed 80 °C, an aluminium bushing was designed to be installed inside the toroid sensor. The temperatures of the toroid sensor were thereby always controlled to be no more than 45 °C, the aluminium bushing under 37 °C during baking, as shown with purple and pink lines, respectively.

The pressure of the DCCT chamber has been bake-tested. As figure 8(b) shows, the results indicate that the final pressure of the DCCT chamber can achieve less than 2×10^{-10} mbar to meet the UHV specification.

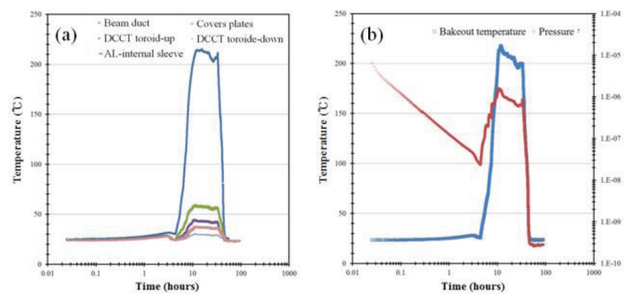

Figure 8: (a) Each temperature distribution for the DCCT chamber; (b) Pressure curve vs. time for the DCCT chamber during bake-out at 200 °C.

CONCLUSION

The DCCT assembly has been prepared, tested and finished to be stored in a vacuum state. It will be installed at the electron storage ring to measure the average beam current. The fabrication and test results shown are summarized as follows. The manufacturing, welding and assembly of the DCCT system have been established. All the welds show a leakage rate less than 1.6×10^{-10} mbar L s^{-1}; related electrical testing has been performed with satisfactory results. Through the baking, the final pressure of the DCCT achieves less than 2×10^{-10} mbar, to meet the UHV specification.

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[1] http://www.bergoz.com/products/NPCT/NPCT.html.
[2] K.B. Unser, "Beam current transformer with DC to 200 MHz range," IEEE Trans. Nucl. Sci., NS-16, June 1969, pp. 934-938.A.

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